Element 1
Powering Innovation

Element 1 Corp (e1)

Methanol to H_2 Supply Systems (MHSS)

- Fuel Cell Mobility -

Robert Schluter, President

CaFCP Working Group Meeting

31 July 2019

Scalable.
Reliable.
Affordable.

Introduction

- e1 is a developer of Methanol to H_2 Supply System **(MHSS)** products and technology
- CaFCP's Stated Goals:
  - Replace gasoline and diesel with clean H_2
  - Accelerate market adoption of consumer FCEV
  - Realistic H_2 solution for HD FCEV
  - Have California lead the way to volume commercialization of fuel cell transportation, enabling market adoption of fuel cell solutions globally

e1's MHSS Technology Accelerates the Adoption of Fuel Cell Solutions Globally

Element 1 Corp

Background

Scalable, Reliable, and Affordable H_2 Generation

- e1 is a leading developer of small-scale advanced methanol to H_2 supply systems supporting the fuel cell industry
- e1 collaborates with its strategic licensing partners to produce state-of-the-art H_2 generation systems used in clean energy solutions
- e1 technology is licensed to partners to address a wide range of products, markets, and applications
- e1 offers solutions for:
  - On-site H_2 generation (fuel cell power, H_2 refueling stations)
  - Mobile (on-board) H_2 generation (fuel cell electric HD trucks, trains, and marine vessels)

Founded in 2010 in Bend, Oregon

Element 1 Corp Introduction Video (Hyperlink)

e1 Business Model

Customer Profile

- Develop H_2 technology
- Assemble and provide sample (demonstration) products for evaluation by partner companies
- **Licensing business model** to get product to market worldwide (**not** a commercial manufacturer of H_2 generators)
- License partners manufacture e1 H_2 generator products and provide the sales channel to defined markets
- **e1's Customer Profile:**
  - Fuel cell technology developers
  - Fuel cell system integrators
  - Market leading OEM's who want to acquire fuel cell related technology to maintain or grow market share

e1 H_2 Generators have been integrated with PEMFC's by:

BALLARD®

HYDROGENICS
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Intelligent Energy

Nedstack
PEM FUEL CELLS

Horizon
Fuel Cell Technologies

altergy®
Leading the Fuel Cell Revolution

Top+ energy
Toplus Energy Corporation

Solving "The H_2 Challenge"

The Case for ***Methanol to H_2 Supply Systems*** (MHSS)

- Fuel cell solutions are being commercialized in the transportation industry
- Fuel cell systems require new H_2 solutions to "***Crack*** the H_2 Challenge"
- Lowering H_2's total cost per kilogram at the point of use is key to ***driving*** adoption of fuel cell power solutions
  - Compressed H_2 is >$8 kg, and can approach $16 kg in key markets ***slowing*** adoption of fuel cell vehicles
- Compressed H_2 occupies ***too much*** volume to be practical for HD transportation (Trucks, Trains, and Marine Vessels)
  - Limited space is available for H_2 storage which ***reduces range***

e1's H_2 supply technology ***Solves*** "The H_2 Challenge"

Methanol

Overcomes Energy Storage Limitations

A high-volume commodity liquid hydrocarbon fuel (methanol) allows for:

- → ***High-energy*** fuel density
- → ***Low-cost*** of fuel (with the right technology)
- → ***Low-cost*** of liquid fuel storage
- → ***Low-carbon*** fuel, with a ***renewable future*** – Just like H_2 and RNG
- → ***Reduces*** Safety Risk – ***No*** onboard HP H_2 storage required
- → Fueling stations wherever ***fueling exists today***

Requires e1 MHSS technology to unlock the H_2 in methanol

Distributed H_2 Generation Solutions

Three H_2 Generator Options

Definition: A completely self-contained machine that converts feedstock to purified H_2

→ **Electrolyzer** (water split by electricity into H_2 and oxygen)
- Requires MW scale power that may not be available
- ***High CapEx and OpEx,*** limiting deployment

→ **Natural gas reformer** (methane plus water reacted to make H_2)
- Requires NG pipeline infrastructure, eliminating remote and mobile solutions
- ***High CapEx.*** High temperature reforming requires special allows, expensive NG conditioning and compression, complex controls, PSA. ***All limiting deployment***

→ **Methanol Reformer** (methanol plus water reacted to make H_2) (***MHSS***)
- ***Lowest*** CapEx due to low temperature reforming, e1 purifier
- ***Lowest TCO***, MHSS cost of produced H_2 about US$3 to US$4/kg
- ***No Supporting*** infrastructure required for ***Onboard the vehicle MHSS***

e1's MHSS products have the *lowest* CapEx, and produces the *lowest* total cost of H_2

e1 H_2 Generator (MHSS) Products

Common Attributes of e1's MHSS technology

- e1 offers three MHSS product lines that operate on a methanol-water mix
- e1 models provide H_2 production flow rates from 2 kg/d to 500 kg/d, all producing fuel cell grade H_2
- e1 H_2 generators are modular and highly scalable while maintaining their breakthrough economics
- **Common attributes:** Very Low CapEx, Very Low OpEx, Lowest TCO H_2 kg/d, Compact Design, Low Noise, Low Maintenance, and No SO_x, No SO_x, or PM

e1 MHSS products have been integrated with PEMFC's by:

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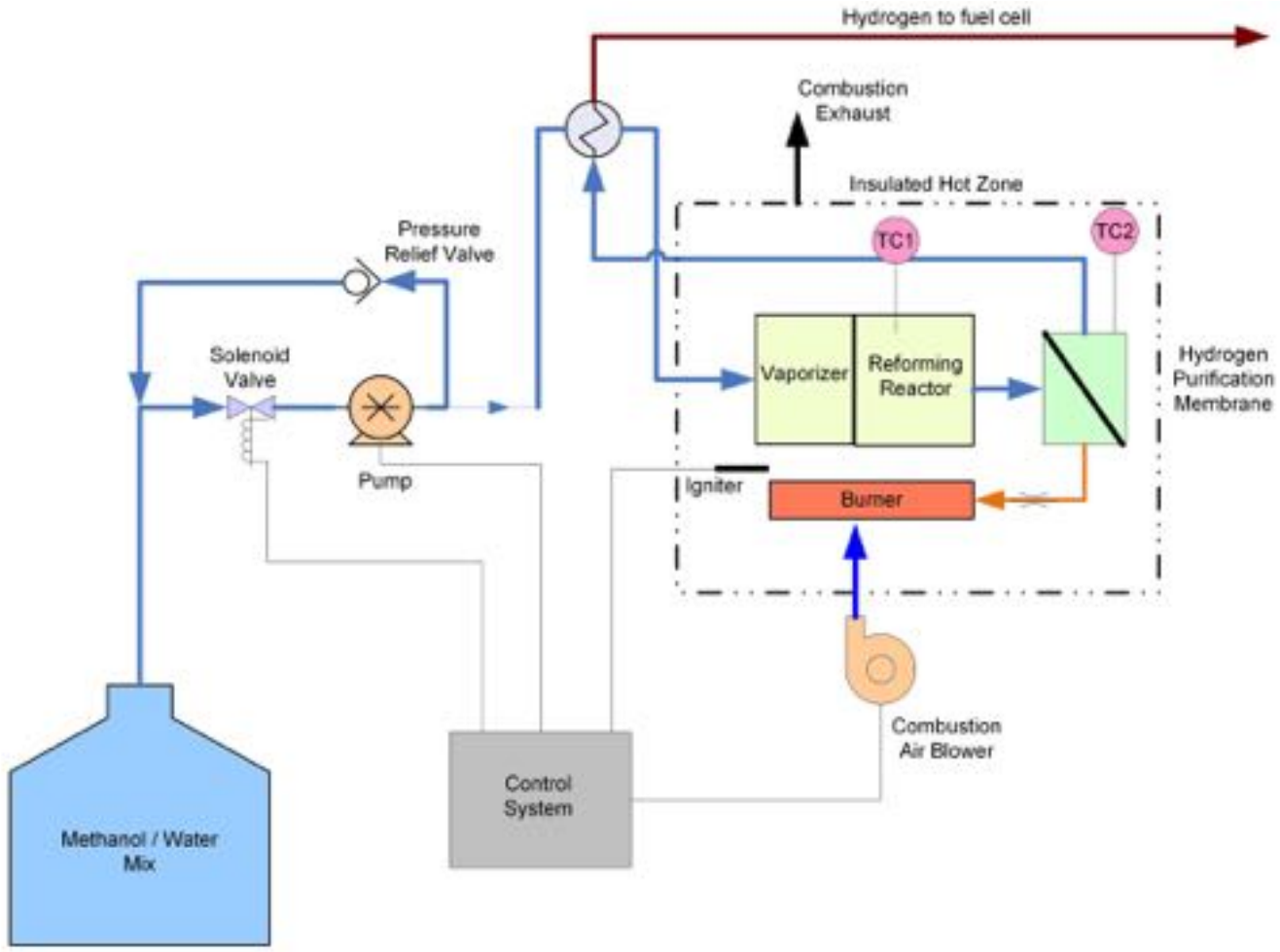
e1 MHSS

Same Fundamental Design; Small to Large

Key Features

- Two input streams (methanol/water mix and combustion air)
- Two output streams (product H_2 and combustion exhaust)
- Thermally integrated (only one control point required)
- Redundant ignition sources
- Starts producing H_2 within seconds (from hot standby)
- Simple, inexpensive to manufacture
- Compact, simple to operate and control



e1 H_2 Membrane Purifier

Patented Proprietary H_2 Purification

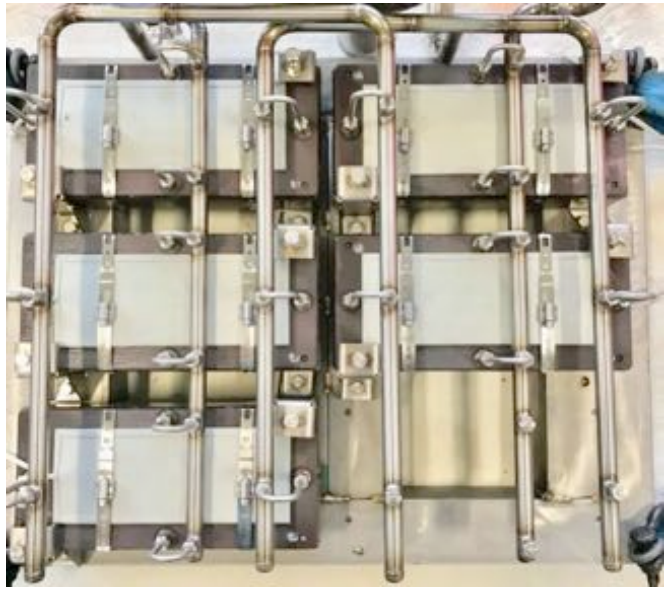
Overview

- e1's membrane purifier was designed to displace expensive micro-PSA H_2 purifiers
- **Operation:** Passive process works by pressure differential
- **Product H_2:** >99.97% (typically 99.99%) with <0.2 ppm CO and <0.2 ppm CO_2
- **Target uses:** H_2 generators, industrial H_2 applications, chemical processes

Key Advantages

- **High Quality:** Produces fuel-cell-grade H_2
- **Lowest initial cost of equipment**
- **Quiet and simple operation:** No moving parts
- **Scalable:** 5 purifiers in an M40, 10 purifiers in M80
- **High reliability and long lifetime:** engineered for > 20,000 hours operation
- **Easy integration:** no valves, absorbents, or complicated controls

Developed over 30 years, e1's membrane purifier is the **Key** to low cost H_2 purification



Purification module array

Section Break

L-Series MHSS
for
H_2 Refueling Stations

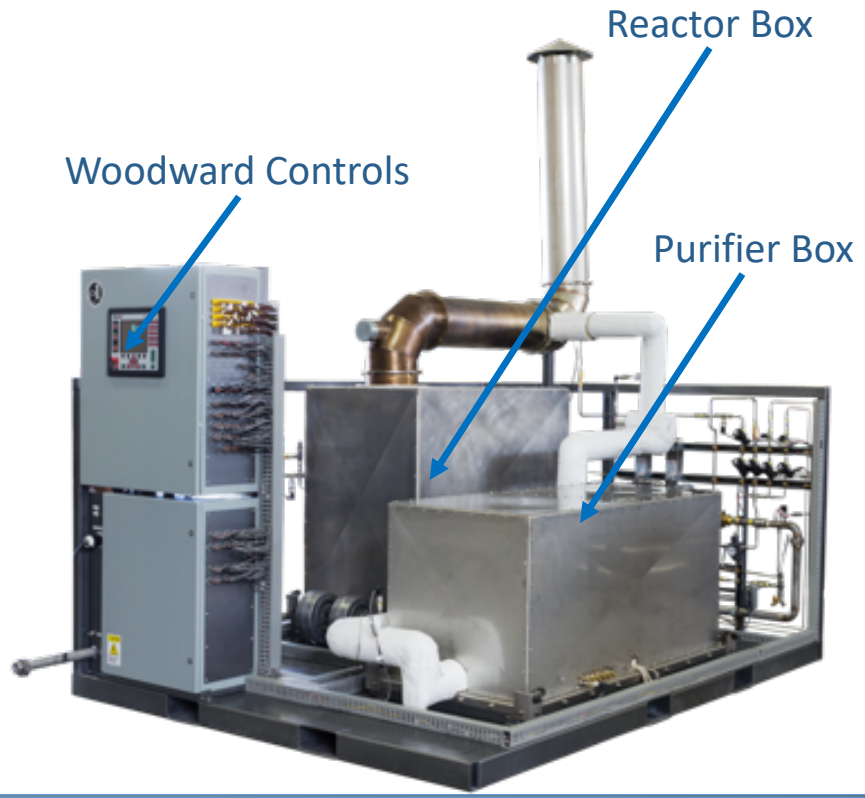
L-Series MHSS

Overview

Designed to displace compressed or liquid H_2 to support H_2 fueling and stationary power

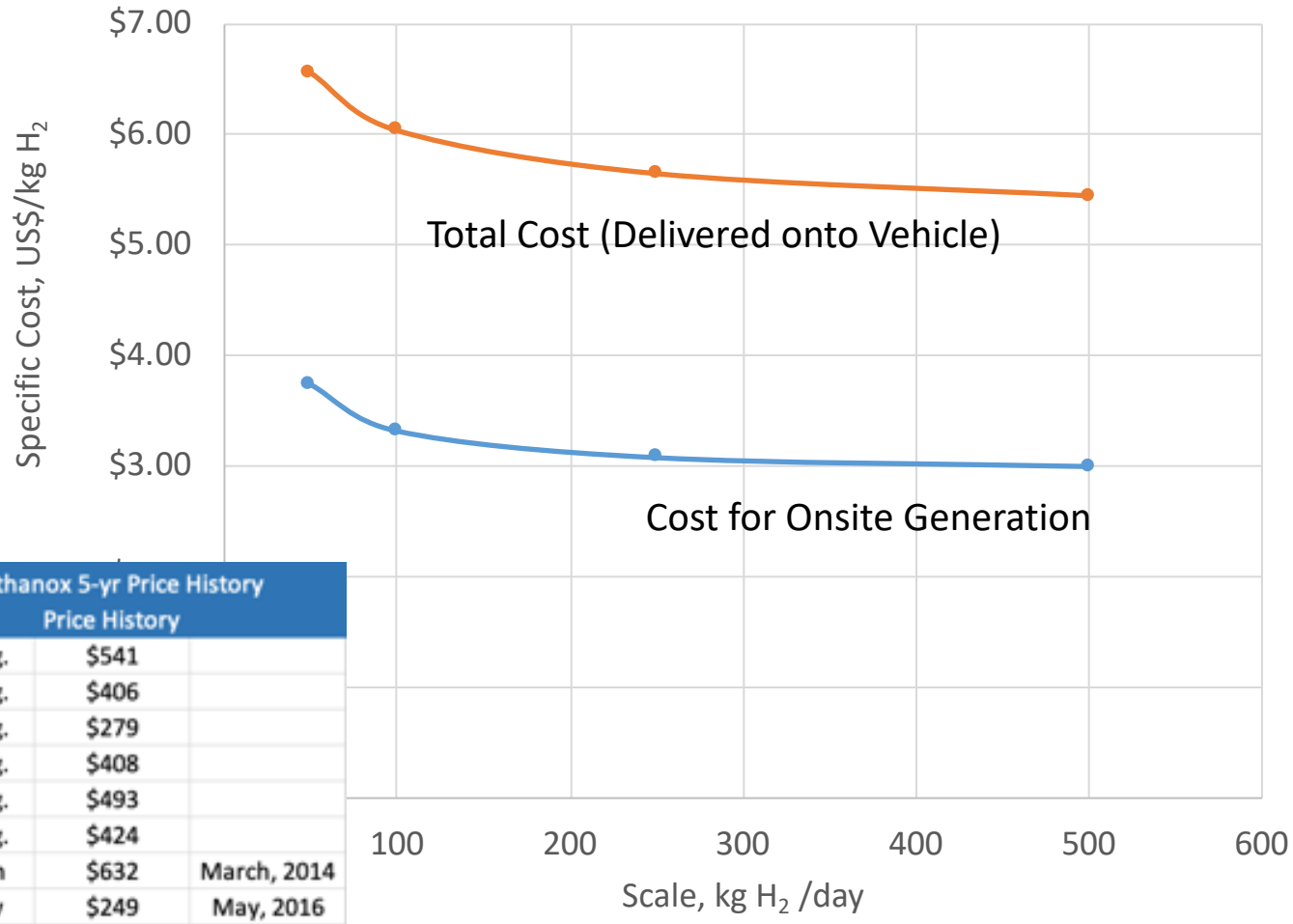
The L-Series MHSS Provides the Lowest Total Cost of H_2 for HRS

- **H_2 Production:** Can scale to produce 50 kg/d to 500 kg/d
- **Woodward Controls:** World-class controls for reliable operation
- **Power Required:** ≤ 6 kW per 500 kg/d of H_2 produced
- **Feedstock:** Methanol and DI water
  - 6.3 kg methanol/water mix water yields 1.0 kg pure H_2
- Displaces expensive H_2 produced offsite
- Competing electrolyzer solutions are expensive and have large electricity requirements that may not be available
- L-Series H_2 generator targets **HRS** and large stationary fuel cell power solutions



Total Cost of H_2, US$/kg

An Affordable Solution for Onsite H_2 Fueling



Methanox 5-yr Price History		
Price History		
2014 Avg.	$541	
2015 Avg.	$406	
2016 Avg.	$279	
2017 Avg.	$408	
2018 Avg.	$493	
2019 Avg.	$424	
5-yr High	$632	March, 2014
5-Yr Low	$249	May, 2016
5-yr Avg	$408	

L-Series H_2 Generator

- **Total cost for H_2 delivered onto vehicle includes:**
  - L-Series H_2 Generator costs (below), *plus*
  - Amortization of CapEx for H_2 compressor
  - Amortization of CapEx for H_2 storage and dispensing
  - Electricity for compression
  - Maintenance
- **Cost for onsite generation includes:**
  - Amortization of CapEx for the L-Series H_2 Generator (5-year depreciation)
  - Cost of methanol feedstock (Methanex 5-yr Avg. US$408/ton)
  - Maintenance

L-Series Provides Significant Cost Reduction

40%+ Reduction on the Cost of H_2

US$/kg

Cost of H_2 at Site

US$8 to $12/kg

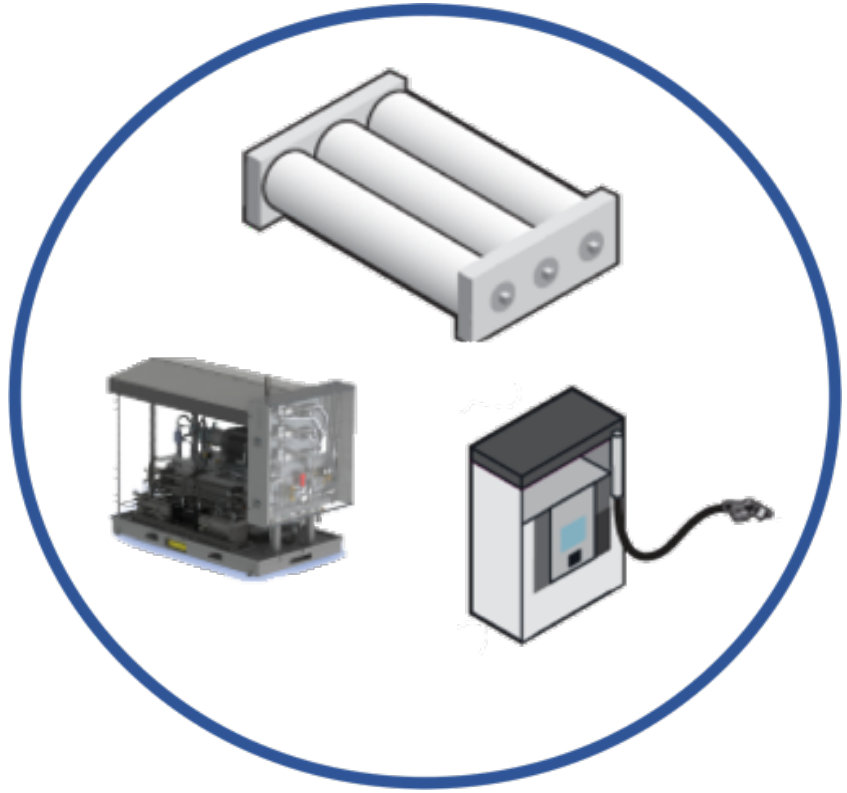
H_2 Gas

US$5 to $8/kg

Electrolysis

US$3 to $4/kg

Compression, storage, and dispensing are common for all solutions



L-Series Compared to Electrolyzer

e1 L-Series

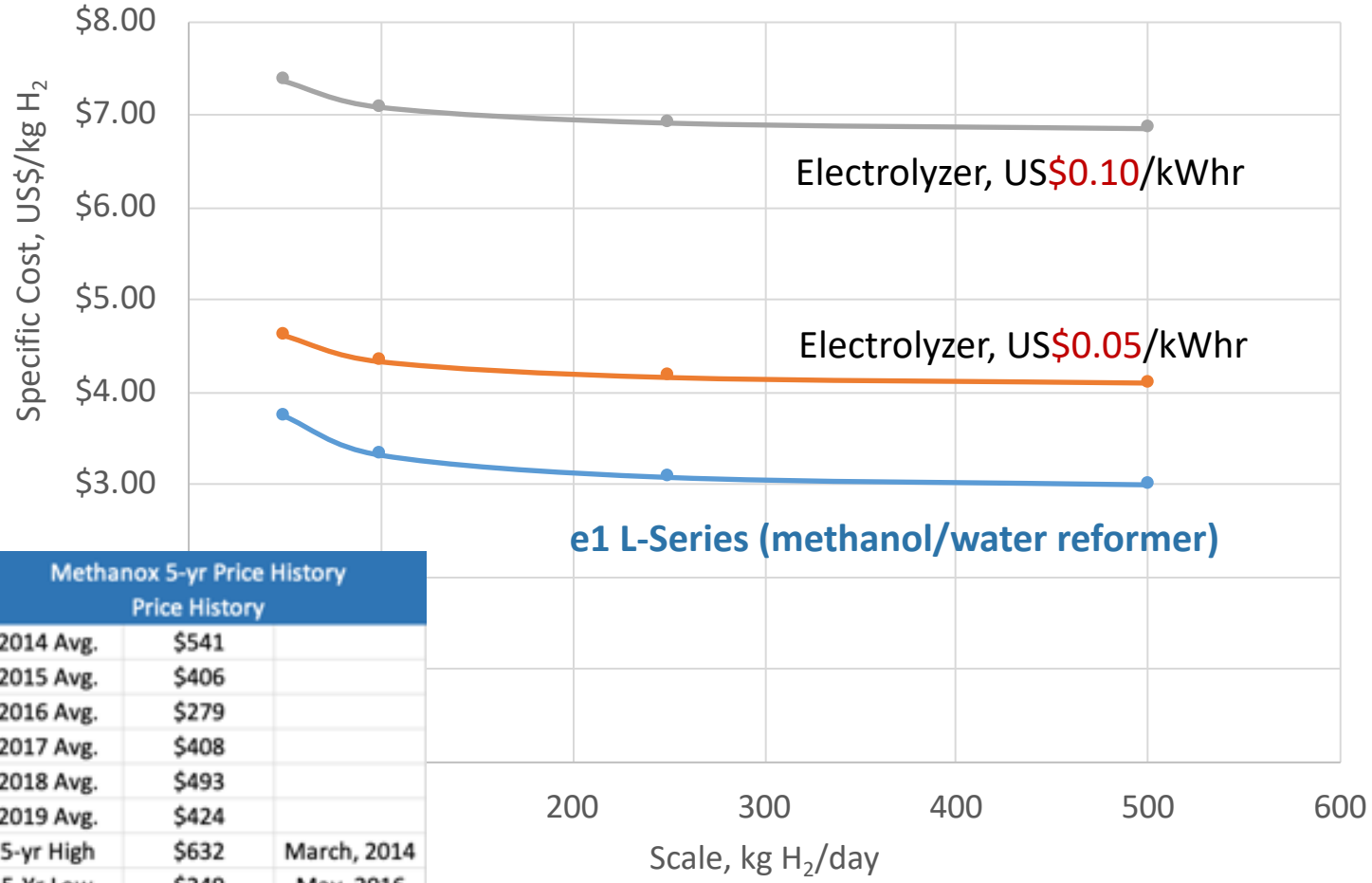
- **Pure H_2 produced from methanol & water**
  - 6.3 kg methanol yields 1.0 kg pure H_2
  - At US$408/ton methanol → 6.3 kg methanol costs US$2.57
  - Minimal maintenance cost
- **CapEx is less than 35% to 50% that of electrolyzers**
  - In commercialization, CapEx is estimated to be:
    - $100,000 to $150,000 for 100 kg H_2/day
    - $250,000 to $300,000 for 300 kg H_2/day
- **If renewable methanol is used, zero net CO_2 emissions**

Electrolyzer

- **Pure H_2 produced from electricity & water**
  - 55 kWhr electricity yields 1.0 kg pure H_2
  - At US$0.10/kWhr → 55 kWhr costs US$5.50
  - At US$0.05/kWhr → 55 kWhr costs US$2.75
  - Significant maintenance cost to deliver high-purity water to the electrolyzer
- **High CapEx**
  - Approx. $560,000 to $750,000 for 100 kg H_2/day
  - Approx. $950,000 to $1,400,000 for 300 kg H_2/day
- **If renewable electricity is used, zero net CO_2 emissions**

Cost of H_2

L-Series compared to Water Electrolyzer



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Cost of making H_2 onsite

(excludes cost of compression, high-pressure storage, and dispensing)

→ **L-Series H_2 Generator costs include:**

- Amortization of CapEx for the L-Series H_2 generator (5-year depreciation)
- Cost of methanol feedstock (US$408/ton)
- Maintenance

→ **Water Electrolyzer costs include:**

- Amortization of CapEx for the water electrolyzer (5-year depreciation)
- Cost of electricity (see graph)
- *No cost included* for maintenance and for water purification

Section Break

M-Series MHSS
Onboard Mobile Solution
for
HD Vehicles, Rail, Marine Vessels

Break-through Solution for HD Fuel Cell Vehicles

Onboard Methanol to H_2 Supply System (MHSS)

Problem

- Heavy-duty fuel-cell vehicles cannot store enough compressed H_2 to achieve target distance between fueling
- H_2 fueling infrastructure is lacking, expensive to build
- High-pressure compressed H_2 presents safety risk, and limits vehicle routes in some jurisdictions

Solution

- Convert methanol/water mix to high-purity H_2 onboard heavy-duty vehicles

M-Series MHSS

On-Board H_2 Generation for ***HD Transportation***

Designed to displace compressed H_2 to support mobile fuel cell propulsion solutions

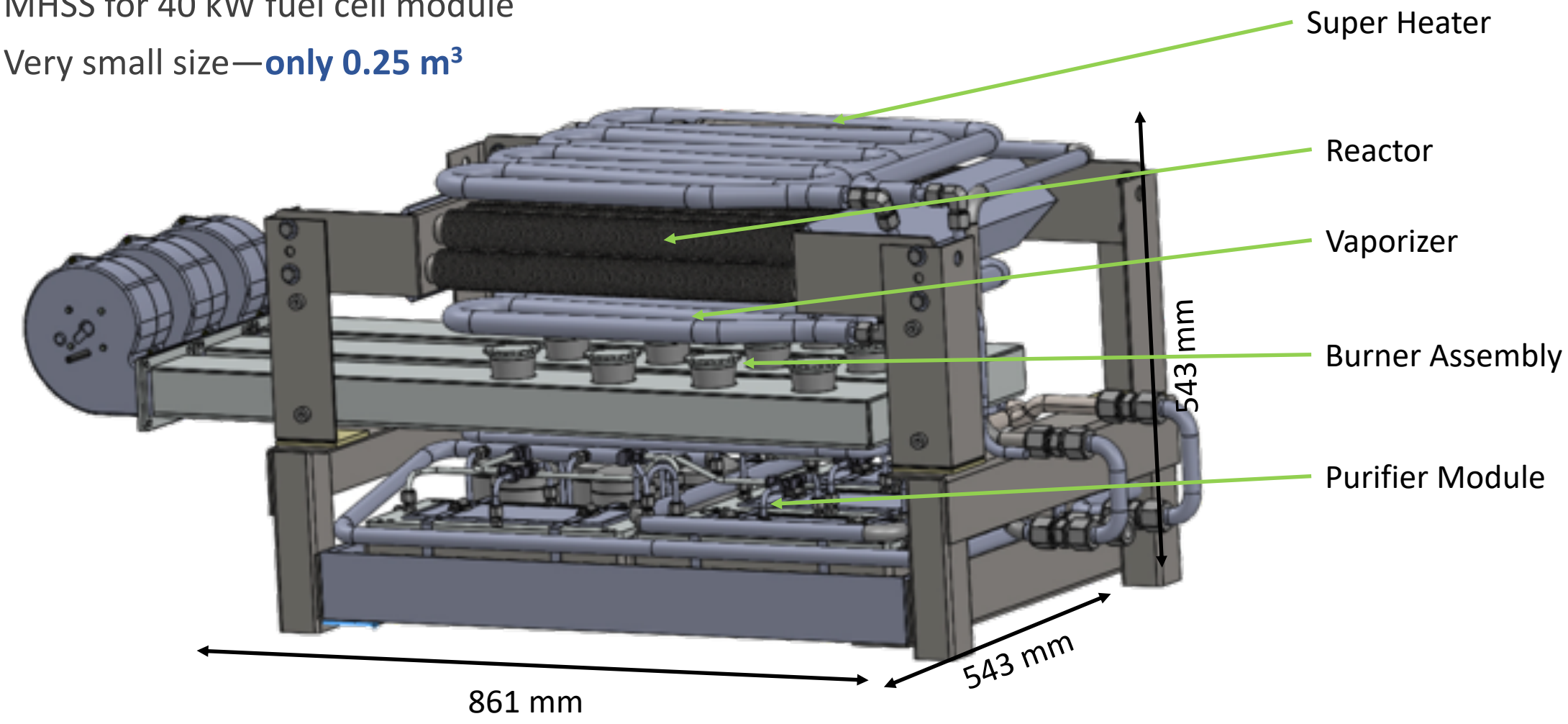
- → **Mature Technology:** Developed over 20+ years, multiple product lines
- → **H_2 Production:** Can scale to support 30 kW to 300 kW fuel cell solutions
- → **H_2 Purity:** >99.97% with <0.2 ppm CO and <0.2 ppm CO2
- → **Vibration Resistant:** Designed for transportation applications
- → **Operation:** Designed for cyclic and variable operation
- → **Feedstock:** Methanol and DI water
  - 6.3 kg methanol/ mix water yields 1.0 kg pure H_2
- → **Lifetime:** Designed for greater than 20,000 hour lifetime (H_2 production)
- → **Manufacturing:** Under e1 manufacturing license

Scalable.
Reliable.
Affordable.

MHSS – M40

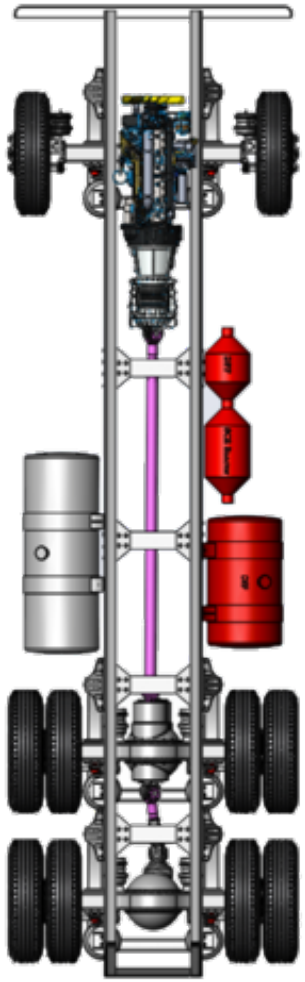
Preliminary 3D Models

- MHSS for 40 kW fuel cell module
- Very small size—**only 0.25 m³**



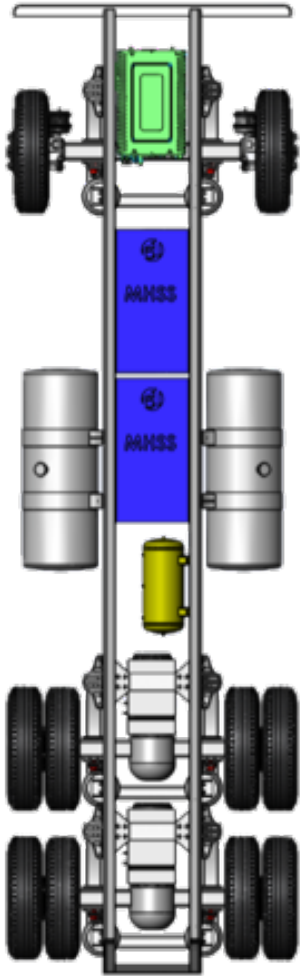
Space Required on HD Truck for 1,000 mile Range

MHSS ***Most Comparable*** to Diesel Solution



Diesel Solution

- SCR (Catalytic Reactor) & DPF (Particulate Filter) already on truck
- Long driveshaft make space between rails unusable
- One 150 gallon side tank
- ***143*** gallons needed for 1,000 mi. range



(Simulation)

e1 MHSS Solution

- Engine Bay and majority of area under cab available for 80 kW fuel cell system
- MHSS (X2) fits between rails where driveshaft previously took space
- Two 150 gallon side tanks
- ***257*** gallons needed for 1,000 mi. range
- Back of cab could also be used for MHSS

Impractical to fit enough compressed H_2 tanks onboard a HD truck to store ***101*** kg of H_2 to achieve 1,000 mi. range

MHSS – Space Reduction

Specific Example

About 2x space reduction onboard heavy vehicle is achieved by using methanol mix plus e1 MHSS

	Range (km)	H_2 (kg)	Storage, 35 Mpa (m^3)	Methanol Mix (m^3)	Methanol Mix + MHSS
Bus	500	32.5	3.5	0.4	2.8
Bus	700	45.5	5	0.5	3
Nikola One, Toyota/Kenworth	1,000	89.3	9.5	0.5	4

Fuel Cost Comparison

MHSS Provides the ***Lowest*** Total Cost of Fuel Per Mile

Fuel Costs (Dollars)	Diesel [1]	CNG [2]	H_2 Gas [3]	MHSS [4]
Per Gallon [(5)]	$ 3.15	$ 2.11	$ 14.08	$ 1.26
Per DGE	$ 3.15	$ 2.40	$ 15.99	$ 2.85
Per H_2 kg Eq.	$ 2.76	$ 2.10	$ 13.99	$ 2.49
Per 1,000 Miles	$ 450	$ 363	$ 1,409	$ 324
Per Mile	$ 0.45	$ 0.36	$ 1.41	$ 0.32

(1) eia US Energy Information Administration, https://www.eia.gov/petroleum/gasdiesel/
(2) CNG Now, http://www.cngnow.com/average-cng-prices/pages/default.aspx
(3) California Fuel Cell Partnership, https://cafcp.org/content/cost-refill
(4) Methanex, https://www.methanex.com/our-business/pricing
(5) Diesel is DGE gallon, CNG is GGE gallon, H_2 is GGE gallon, MHSS is methanol gallon

MHSS & methanol reduces the cost per mile by > ***25% vs Diesel***

e1 M-Series MHSS H_2

Key Advantages

1. **Occupies smaller space on the vehicle compared to compressed H_2:**
   - Result is greater driving range between fueling
2. **Very Low TCO:**
   - Very low CapEx and OpEx, produce H_2 for $3 to $4 per kg onboard the HD Truck
3. **Reduced Emissions:**
   - ***No*** NOx | ***No*** SOx |***No*** PM (Soot)| CO_2 emissions significantly reduced. (***zero net*** CO_2 if renewable methanol is used)
4. **Scalable:**
   - Support 30 kW to 300 kW fuel cells per MHSS module
5. **Simple / Familiar Feedstock Storage:**
   - No stored high-pressure H_2 required, improved safety

Extreme cold weather operation available with methanol

Accelerates the Adoption of Fuel Cell HD Trucks

Take Away…..

……Moving Forward

- Gaseous H_2 has significant limitations in regards to logistics, infrastructure, cost, and is ***not*** practical for HD transportation
- Liquid methanol is a low carbon fuel and provides high H_2 density, low-cost liquid logistics and storage, reduced safety risk versus compressed H_2, and ***is practical*** for HD transportation
- e1's MHSS ***unlocks*** the benefits of methanol and ***solves the "H_2 Challenge"***
  - Stationary L-Series solution for HRS provides the lowest TCO for H_2 per kg at the point of use
  - Mobile M-Series solution for HD transportation supports extended range requirements, allows for typical vehicle missions, and significantly reduces the investment in HRS
- With renewable methanol and e1's MHSS products, you are driving towards a zero-emission sustainable future

Deploying e1's MHSS products will Accelerate the Adoption of Fuel Cell Solutions

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Reliable.
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Element 1
Powering Innovation

The End

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